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Comments on “A Supernova Brane Scan”

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Abstract

Recently we proposed that the acceleration of the Universe could be due to gravity leaking to extra dimensions. This scenario gives an alternative to the cosmological constant or quintessence. In [astro-ph/0106274] the authors claimed that this proposal is strongly disfavored if not ruled out by the existing data on Supernovae, Cosmic Microwave Background and clusters. We show that the work [astro-ph/0106274] contains incorrect statements in the theoretical part, and, moreover, we argue that the main conclusions of the work concerning the comparison with the data are premature.

In Ref. [1] we proposed a brane-world scenario in which the late time acceleration of the Universe is due to the fact that gravity at ultra-large distances becomes five-dimensional and can leak into the extra fifth dimension. This proposal is an alternative to the cosmological constant or quintessence scenarios for the accelerated Universe. It is based on a brane-world model of Ref. [2], and on a subclass of cosmological solutions found in Ref. [3].

We analyzed qualitatively in [1] the Supernovae and Cosmic Microwave Background data. The analysis in [1] indicated that the existing data cannot discriminate between our model and standard cosmology, but the results of further precision measurements might do so. The next step is of course the confrontation with the real data.

Recently, the authors of Ref. [4] claimed that the model [2], and the proposal [1] is strongly disfavored if not ruled out completely by the existing data on Type Ia Supernovae, Cosmic Microwave Background and clusters. The purpose of the present note is to discuss the work of Ref. [4]. In particular, we will argue that these claims are premature.

First we briefly review the main features of the model [2] and then turn to our proposal [1].

The model of Ref. [2] describes a four-dimensional (4D) world which is confined to a hyper-surface (a “brane”) in five-dimensional (5D) space with infinite flat extra dimension. The electromagnetic, weak and strong interactions are “stuck” to the brane hyper-surface, however gravity is an exception and can propagate everywhere in the whole 5D space. As a result, the gravitational interactions are different in our 4D world: Gravity behaves in a conventional Newtonian way at observable distances, however, the interactions are modified at ultra-large cosmological distances where they become five-dimensional.

From the phenomenological standpoint, there is one free parameter in the model of [2], that is the 5D gravity scale $M_{(5)}$. The latter controls the crossover distance r_c between the conventional 4D and unconventional 5D regimes:

$$r_c = \frac{M_P^2}{2M_{(5)}^3}, \quad (1)$$

where $M_P \sim 10^{18}$ GeV is the reduced 4D Planck mass. For distances r smaller than r_c gravity is conventional and gives the $1/r^2$ Newton law. However, for distances bigger than r_c this breaks down and gravity enters the 5D regime. As was pointed out in Ref. [5], and shown in detail in Ref. [6] the high-energy particle processes, astrophysical constraints and the results of sub-millimeter gravitational measurements put the lower bound on $M_{(5)}$, that is $M_{(5)} \gtrsim 10^{-3}$ eV. On the other hand, the requirement that the cosmological evolution be conventional four-dimensional until the late times requires that $M_{(5)} \lesssim 10$ MeV. Thus, we have the following range for the parameter $M_{(5)}$:

$$10^{-3} \text{ eV} \lesssim M_{(5)} \lesssim 10^7 \text{ eV}. \quad (2)$$

Using (1) these constraints on $M_{(5)}$ translate roughly into the following admissible range for the crossover distance r_c :

$$10^{29} \text{ cm} \lesssim r_c \lesssim 10^{59} \text{ cm} . \quad (3)$$

Thus, the lowest possible value of r_c is of the order of present-day horizon size.

Different values of r_c are interesting from a different perspective. A model with $r_c \sim 10^{59} \text{ cm}$, i.e., with $M_{(5)} \sim 10^{-3} \text{ eV}$, predicts a deviation from the Newtonian gravity at very small sub-millimeter distances (see detailed discussions in [6]) where the Newtonian gravity is just being tested experimentally [7]. For this value of r_c , in order to obtain the accelerated Universe one has to add a cosmological constant or a quintessence field on a brane. In this case, the model of [2] cannot be distinguished from the conventional 4D scenario on the basis of cosmological arguments (but it can be distinguished in sub-millimeter measurements of the gravitation law).

From the point of view of cosmology it is interesting to consider another range of the parameter space in Eqs. (2), (1), that is $M_{(5)} \sim 10^7 \text{ eV}$, i.e., $r_c \sim 10^{29} \text{ cm}$. As was discussed in Ref. [1] there are interesting cosmological predictions for this value of the parameter $M_{(5)}$ if one uses the self-accelerated cosmological solution of Ref. [3].

After this brief introduction we comment on the results of Ref. [4].

The first comment concerns the statements made in the abstract, introduction and conclusions of [4] claiming that the model of [2] (which the authors of [4] call the DGP model) is ruled out by the cosmological data. This statement is false since the model of [2] can in no way be ruled out by cosmology as we just discussed. Indeed, for the most part of the parameter space in (2) the model of [2] predicts no changes in conventional 4D cosmology. For instance, if $M_5 \sim 10^{-3} \text{ eV}$, the crossover scale r_c is about 30 orders of magnitude bigger than the present day horizon size and the cosmology of the model [2] is identical for all the practical purposes to the conventional 4D cosmology.

Let us now turn to the proposal of Ref. [1]. There we chose the lowest possible value of the parameter $r_c \sim 10^{29} \text{ cm}$. In this case the modification of gravity takes place at the size of the present day horizon. We confined ourselves to a particular cosmological solution with self-acceleration which was found in Ref. [3] and proposed in [1] to use this solution for the description of the Supernovae data on the acceleration of the Universe [8]. It is only this proposal which could be ruled out in principle in [4] by the cosmological data. In other words, cosmological considerations could rule out the part of the parameter space of the model [2] with $M_{(5)} \sim 10 \text{ MeV}$, but not the model of [2] itself as claimed in [4].

Moreover, we will argue below that given the state of the current data the proposal of [1] cannot be favored over the conventional scenarios, and certainly cannot be disfavored or excluded, in contrast with the conclusions of Ref. [4]. We will turn to this momentarily after a minor digression in the next paragraph.

Here it is appropriate to make one more comment on the claims of Ref. [4]. Authors of [4] state that one cannot accommodate on a brane with infinite extra space

the closed ($k = 1$) universe since the latter requires a finite volume. Although this issue has only an academic interest (as the current data supports the flat Universe with $k = 0$), nevertheless, for the sake of completeness we will comment on this. The statement of [4] is not correct since the $k = 1$ solutions can be accommodated on the brane along the lines of Refs. [3],[9]. Since this is just a straightforward rewriting of the equations of Refs. [3],[9] for the $k = 1$ case we will not repeat them here. It seems that the authors of [4] did not realize the fact that even if the volume of the extra space is infinite, this *does not mean* that the 3D volume of the observable braneworld Universe should also be infinite ¹.

The cosmology of the model considered in [1] is governed by the following first Friedmann equation

$$H(z)^2 = H_0^2 \left\{ \Omega_k(1+z)^2 + \left(\sqrt{\Omega_{r_c}} + \sqrt{\Omega_{r_c} + \Omega_M(1+z)^3} \right)^2 \right\}, \quad (4)$$

where Ω_{r_c} is defined by $\Omega_{r_c} \equiv (2r_c H_0)^{-2}$ and the only energy-momentum content of the universe is non relativistic matter (and no cosmological constant). The Friedmann equation is thus non standard as is the normalization condition ²

$$\Omega_k + \left(\sqrt{\Omega_{r_c}} + \sqrt{\Omega_{r_c} + \Omega_M} \right)^2 = 1. \quad (5)$$

The outcome of equation (4) is that the early cosmology is standard matter-dominated, whereas the late time cosmology exhibits acceleration when the matter density becomes small enough. This late time behavior enables to explain the Supernovae observations [8] without the need of a cosmological constant or quintessence field [1].

Let us now turn to the issue of comparison with the data.

As it is easy to see from the plots presented in Ref. [1] one needs a lower value of Ω_M than in standard cosmology in order to fit the SN data in our model. Our current estimate [11], which is based on a fit of 54 Supernovae (18 nearby and 36 distant, taken from second Ref. of [8]) is for a flat universe (as required by CMB observations) at one sigma level

$$\Omega_M = 0.24^{+0.08}_{-0.06}. \quad (6)$$

This should be compared with the number quoted in [4] obtained for our model by fitting 92 Supernovae (at one sigma level)³:

$$\Omega_M = 0.2^{+0.05}_{-0.05}. \quad (7)$$

¹As an additional side comment we just briefly mention that the problem of the extra polarization of the 5D graviton which was discussed in [2] and is a point of concern in [4], was recently resolved in [10].

²Note that Ω_M and Ω_k are defined in a conventional way.

³and $\Omega_M = 0.2^{+0.1}_{-0.1}$ at 99% confidence level

It is at least an overstatement to claim, as in [4], that such numbers are enough to rule out the model on the basis of estimates of Ω_M coming from other means than SN or CMB observations. One can certainly pick a single, least favorable value among these estimates to compare it to our model, as it was done in [4], but this cannot be justified by any scientific means. The value of Ω_M obtained from fitting the data which is quoted in [4] is $\Omega_M = 0.35^{+0.07}_{-0.07}$. Even if one is to accept this value and (7) for granted, one could really wonder whether a two sigma discrepancy is enough to rule out a model, given the state of the art of measurements of Ω_M . The estimates for Ω_M from other means than Supernovae data (and CMB) is far from being settled with such a good precision to rule out (6) or (7). Moreover, it is well known that the different measurements have systematic uncertainties which are very difficult to assign (see for example the discrepancy between the values quoted in [12] and the one obtained by X-Ray or SZ measurements quoted in [4]). We will not comment on this any longer, let a reader decide if numbers such as (6) or (7) are good enough to rule out a model.

On the other hand, as pointed out in [1], it is perfectly true that the model can be disproved with coming data and precision cosmological tests, and this makes it exciting. However, given the status of the current data it does not seem reasonable to make strong statements such as those made in Ref. [4].

Some of us are currently working on a more comprehensive comparison with the data including the large scale structure and CMB results [13].

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References

- [1] C. Deffayet, G. Dvali and G. Gabadadze, [astro-ph/0105068].
- [2] G. Dvali, G. Gabadadze and M. Porrati, Phys. Lett. **B485** (2000) 208 [hep-th/0005016].
- [3] C. Deffayet, Phys. Lett. B **502** (2001) 199 [hep-th/0010186].
- [4] P.P. Avelino and C.J.A.P. Martins “A supernova Brane Scan” [astro-ph/0106274].
- [5] G. Dvali, G. Gabadadze, M. Kolanovic and F. Nitti, hep-ph/0102216.
- [6] G. Dvali, G. Gabadadze, M. Kolanovic and F. Nitti, hep-th/0106058.
- [7] C. D. Hoyle, U. Schmidt, B. R. Heckel, E. G. Adelberger, J. H. Gundlach, D. J. Kapner and H. E. Swanson, “Sub-millimeter tests of the gravitational inverse-square law: A search for ‘large’ extra dimensions,” hep-ph/0011014;

- J.C. Price, in *Proceedings of International Symposium on Experimental Gravitational Physics*, ed. Michelson, Guangzhou, China (World Scientific, Singapore, 1988);
- J. Long, “Laboratory Search for Extra-Dimensional Effects in Sub-Millimeter Regime” Talk given at the International Conference on Physics Beyond Four Dimensions, ICTP, Trieste, Italy; July 3-6, (2000);
- A. Kapitulnik, “Experimental Tests of Gravity Below 1mm” Talk given at the International Conference on Physics Beyond Four Dimensions, ICTP, Trieste, Italy; July 3-6, (2000) .
- [8] A.G. Riess et al., *Astroph. J* 116, 1009 (1998);
 S. Perlmutter et al., “Measurements of Omega and Lambda from 42 High-Redshift Supernovae”, [astro-ph/9812133];
 A.G. Riess, Talk Given at The Symposium “*The Dark Universe: Matter, Energy, and Gravity*” Baltimore, April 2-5, (2001).
- [9] C. Deffayet, G. Dvali, G. Gabadadze and A. Lue, hep-th/0104201.
- [10] C. Deffayet, G. Dvali, G. Gabadadze and A. Vainshtein, hep-th/0106001.
- [11] J. Raux, private communication to be published.
- [12] R. Carlberg, *et al* 1997, ApJ 478, 462;
 N. Bahcall, *et al* 2000, ApJ 541, 1.
- [13] C. Deffayet, S. Landau, J. Raux, M. Zaldarriaga, in preparation.